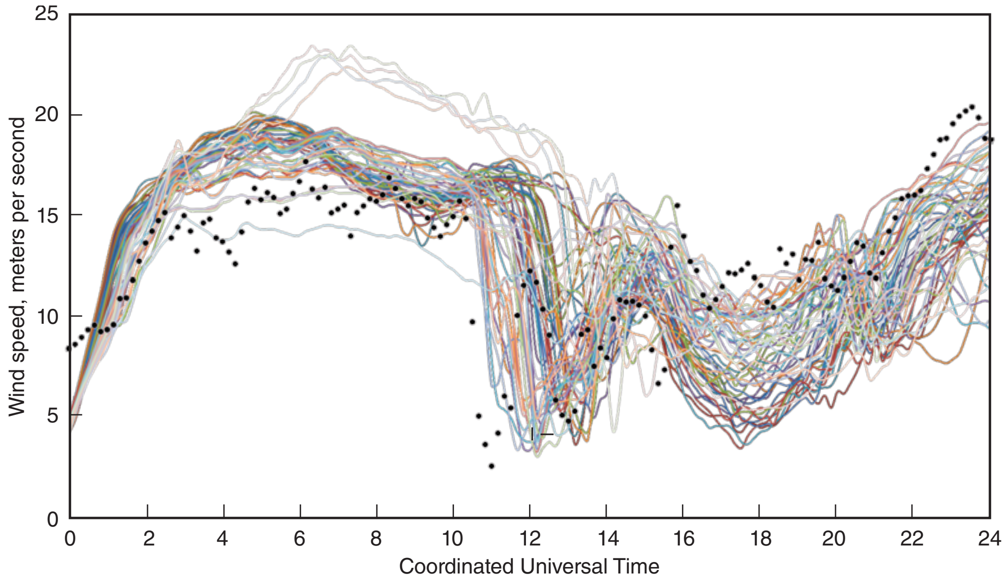
2020 Vision for California's Electric Grid

SCHEDULING the electric generators that supply the grid with power is a balancing act. Each day, system operators evaluate the supply-and-demand conditions forecast for the electric grid for the following day and prepare a generation schedule to satisfy projected demand. (See *S&TR*, June 2013, pp. 4–12.) If operators turn on too many generators, the units will run at only partial capacity, which is inefficient and more expensive than running at full capacity. But if too few are operating when demand spikes, operators will have to engage more generators at the last moment, which also increases costs. If available generators cannot start up quickly enough, power interruptions may result.

California could face more frequent last-minute capacity corrections or even power interruptions as the state implements the ambitious Renewables Portfolio Standard (RPS). This standard requires the state to derive at least 33 percent of its electricity from eligible renewable energy resources by 2020. (See *S&TR*, March 2009, pp. 13–16.) Meeting the RPS goals will involve a sizable boost in wind and solar power generation, but integrating a large number of these intermittent energy resources into the power grid could challenge both generation planning and system reliability.

In 2011, the California Energy Commission funded research at Lawrence Livermore to determine whether new energy storage technologies and demand response initiatives might help balance the load on generators as more solar and wind resources are added to the grid. (See *S&TR*, December 2011, pp. 4–11.) Energy storage systems allow grid operators to more effectively manage the power



A Weather Research and Forecasting multiphysics ensemble of wind speed forecasts (colored lines) and lidar measurements (black dots) over a 24-hour period demonstrate the value of generating multiple forecasts using different physics configurations to capture the uncertainty inherent in wind generation. Only a few of the outlier trajectories capture the early drop in wind speed measured at hour 11, illustrating how a single forecast will often mistime an extreme event. Large-scale ensemble weather modeling is enabled by Livermore's high-performance computing and weather forecasting resources and expertise.

supply when demand is high but wind and solar resources are not generating much electricity. Demand response initiatives offer customers financial incentives to reduce or shift their electricity usage when there is a shortage of power generated.

For this project, a multidisciplinary research team led by computational engineer Thomas Edmunds combined atmospheric forecasting, scheduling optimization, and production simulation to create a comprehensive planning system for electric grid research. By tapping the Laboratory's supercomputing resources to run thousands of simulations, the researchers determined the value of using increased storage and demand response initiatives to keep California's complex grid system operating affordably and reliably.

More Is Better

Efficient scheduling hinges on accurate next-day renewable forecasting, but the generation potential of wind and solar resources is harder to predict than it is for other energy sources. The role of demand response and storage depends on which units are providing electricity at any given time. Addressing uncertainties in both forecasting and scheduling was thus essential to accurately estimate the value of implementing these options.

For this effort, the Livermore team created a multiscale atmospheric model of the western U.S. for use in generating forecasts with the Weather Research and Forecasting (WRF) modeling system. The study year was 2020, but weather data recorded in 2005 provided a starting point for the forecasts. A single day-ahead forecast may not accurately predict the changes in atmospheric conditions that actually occur throughout the day. The team accounted for this uncertainty with a multiphysics modeling approach, running 30 different atmospheric simulations for every 24-hour period. The result was an ensemble of physically plausible weather scenarios for each day of the year.

The simulation predicted weather conditions at 15-minute intervals to capture the precise timing of changes such as wind speed and cloud cover. Completing the daily ensemble forecasts for all of 2020 took approximately 840,000 computational hours on Livermore's supercomputing systems and produced over 500 terabytes of data.

"Our ensemble technique looks at the many ways weather could evolve," says Edmunds. "Other analyses use a statistical model with one weather forecast for each season, which is derived from historical data. Our representations of uncertainty are many orders of magnitude richer than those produced by standard analysis methods." In fact, these computationally intensive approaches have demonstrated a reduction in errors of up to 22 percent in predictions for day-ahead wind generation.

The team used the WRF model and the sets of weather trajectories to calculate next-day generation forecasts for about 5,000 wind and solar generators located throughout the western region. Each day's 30 weather forecasts became 30 solar and wind generation forecasts, each of which was then subtracted from the energy demand. The amount remaining, the net demand, was the portion that needed to be met through unit scheduling of other resources.

Calculations quantified an important relationship between demand and temperature. Starting at 100°F (38°C), each 1° rise in temperature across the territory serviced by California ISO increases electricity demand by 1 gigawatt—equivalent to the output of a large power plant. Because demand changes so quickly at high temperatures, forecast accuracy is especially important on the hottest days. "By running an ensemble of forecasts instead of only one scenario, we are more likely to capture an extreme event," says atmospheric physicist Matthew Simpson.

Intelligent Decision Making

The production simulation model used by California ISO incorporates 2,400 generators and 120 transmission lines and is designed to optimally allocate energy resources for the state's residents. The Livermore team worked with the same WRF model, PLEXOS modeling platform, and CPLEX optimization algorithms as the system operator, but with two additional software features—optimization across multiple timescales and stochastic unit commitment.

"What makes our study special is that we're modeling at multiple timescales," says Livermore mathematician Carol Meyers. "PLEXOS handles all these different scales intelligently." The software simultaneously optimized weekly scheduling for hydroelectric resources, day-ahead and hourly unit commitment for slow-starting generators, and real-time commitment and power-level decisions for quick-starting generators.

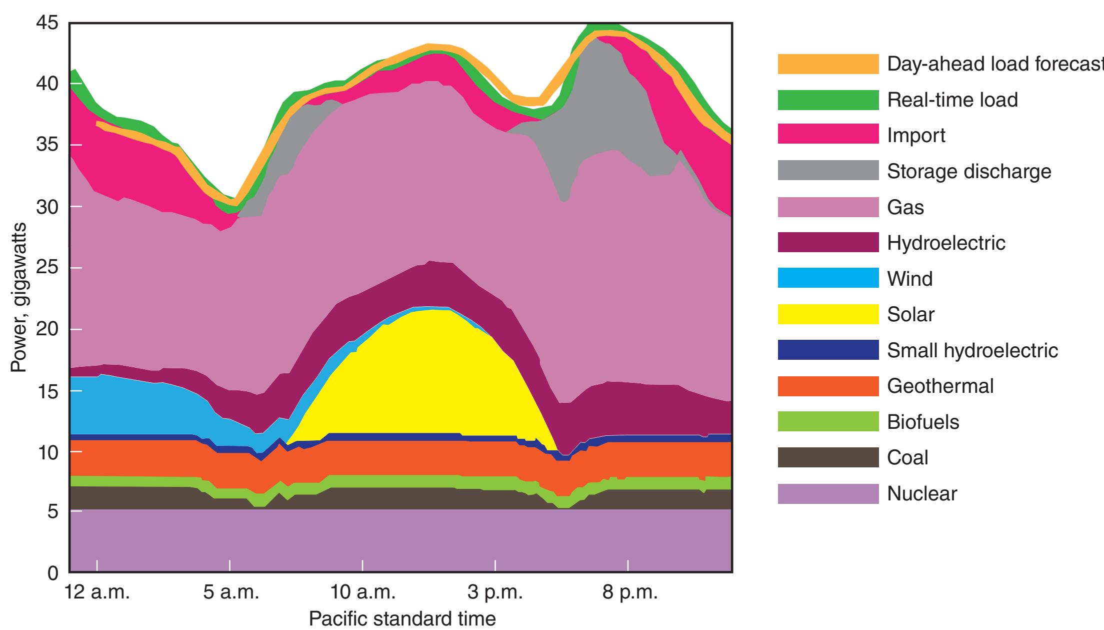
Rather than minimizing cost for a single supply-and-demand trajectory, stochastic unit commitment finds the most economic schedule across a set of probability-weighted forecast scenarios for renewable generation. Resource scheduling involves specifying for every hour of a day whether each generator should be on or off. Problems of this nature, called integer optimization, are computationally intensive, and the calculations balloon when multiple net demand scenarios are considered. To reduce problem size and computing time, the team grouped each day's 30 forecasts using statistical methods and chose five or six representative paths for stochastic unit commitment input.

The California ISO simulation model optimized system operation at 5-minute intervals for each day of 2020, both with and without storage and demand response, to determine which combination of the two options represented the best investment. The solution detailed the operational costs and revenues generated by all resources in the California grid system. In total, the team simulated 3,000 days of electric grid operations. On a high-end workstation, those simulations would have taken more than 8 years, but Livermore's high-performance systems compressed the computing time by a factor of 100, generating results in just 1 month.

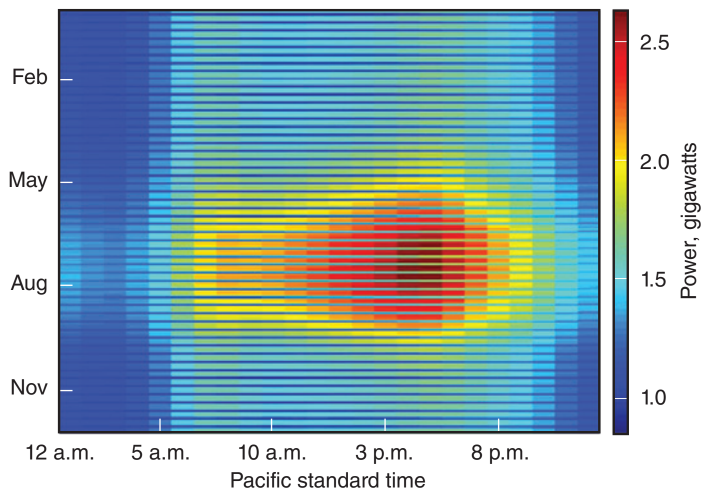
The team's results indicate that either approach alone or in combination will effectively balance resources, but neither one significantly affects revenue. Demand response initiatives reduce total annual operating costs by a little less than 1 percent. The high costs to build storage systems outweigh the revenue provided by storing energy when the price is low and selling it when the price is high. One cause of the low revenues from energy storage is California's mild weather. "Storage value depends on the difference between the lowest and highest cost during the day," says energy economist Alan Lamont. "Most of the time, the differential is not all that large in California."

A Resilient System

The team also analyzed how high quantities of renewables might affect grid performance—specifically, the grid's ability to regulate alternating current frequency second by second under normal operating conditions and to compensate for unexpected events such as loss of a generator or transmission line. Researchers worked with DNV KEMA Energy and Sustainability to develop a simplified version of the company's KERMIT software. The revised software analyzed performance of frequency regulation resources over an entire year and on a sample of days to



Production simulation results for a winter day in 2020 highlight the utility of energy storage systems when demand is high but wind and solar resources do not generate much electricity.



This snapshot of a simulation input shows the demand response capacity available in a given year. In the summer, large amounts of demand response are available to help alleviate energy demands during peak periods. Weekends have low availability (as shown by the "striping" pattern) because the primary program participants, large businesses, are typically closed.

examine how different resource combinations affected system performance overall.

The stability analysis examined potentially challenging periods throughout the year, such as when an especially large fraction of energy was provided by renewables. For this analysis, researchers introduced a 2,000-megawatt loss of generation capacity into the system and compared two scenarios: one without any storage capacity to regulate frequency and a second with 200 megawatts of storage available for regulation. These tests helped determine the effectiveness of various technologies at maintaining a stable and adaptable grid.

The performance study found no significant problems for the range of options considered. "It appears that California's current technology can withstand short-term variations in renewable power generation and delivery," observes electrical engineer Philip Top. "This finding is what we expected, but it was important to see confirmation through the study." The simulations did suggest that grid stability could be compromised if renewable energy sources were to reach levels significantly above the RPS goals. The team's analysis also showed that both demand response programs and flywheels, a type of energy storage, are effective and economically viable options for frequency regulation. In addition, providing regulation using a combination of storage and conventional generation units reduces overall maintenance costs.

Storage systems can make the grid more resilient to shocks as well. A sudden loss of power lowers the frequency throughout the system. Periods when renewables are supplying a large proportion of electricity tend to produce more extreme frequency drops. The Livermore modeling demonstrated that storage systems reduce the severity and duration of such deviations.

Weathering Changes in the Grid

Results from the study indicate that California's electric grid can accommodate a large increase in capacity from renewables, even if energy storage is not widely deployed. The data should also help policy makers determine the best path for achieving the state's RPS goals.

According to Edmunds, the Livermore project is the first to combine physics-based uncertainty modeling of renewable generation with stochastic planning methods to simulate the operation of a highly renewable system. "We are in the vanguard of organizations applying supercomputing to grid optimization problems," he says. "We've shown that our platform can be used to evaluate complementary technologies such as demand response and storage. But what truly made this effort unique was its scope." Modeling a full year of system behavior and accounting for forecasting and energy production uncertainty compounded the project's complexity, but it provided more confidence in the resulting data.

In future studies, Livermore scientists will use this end-to-end planning system to analyze scenarios with more variables and in greater detail than ever before. "Our goal is to evaluate refinements in planning and atmospheric forecasting methods and determine how different configurations of renewable generators affect the energy available throughout the grid system," says Edmunds. "We also are expanding the study to examine geothermal energy as a method of frequency regulation."

Another significant outcome of the project is that it demonstrated the value of ensemble modeling for optimizing complex operations. "Running the California electric grid with 33 percent renewable generation introduces a great deal of uncertainty that needs to be managed effectively," says Lamont. "Current methods of forecasting, scheduling, and dispatching do not account for such high levels of fluctuation. As a result, grid operators could over- or undercommit energy-generation resources on any given day, which might either increase operating costs or lead to power shortages. More sophisticated methods for measuring and incorporating uncertainty will improve the system's efficiency and reliability."

—Rose Hansen

Key Words: California Energy Commission, California ISO, CPLEX code, demand response initiative, energy storage, frequency regulation, integer optimization, KERMIT code, multiphysics modeling, PLEXOS code, renewable energy generation, Renewables Portfolio Standard (RPS), stochastic unit commitment, weather forecast ensemble, Weather Research and Forecasting (WRF) modeling system.

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